

**TITLE: APPARATUS AND METHOD OF REDUCING ANHYDROUS AMMONIA APPLICATION BY OPTIMIZING DISTRIBUTION**

**5 I. CROSS-REFERENCE TO RELATED APPLICATIONS**

This application claims benefit under 35 U.S.C. § 119(e) of provisional application 60/396,763 filed July 17, 2002.

**II. BACKGROUND OF THE INVENTION**

10 Application or injection of chemicals, such as fertilizers, on or into the soil, is commonly used to enhance growth and yield for agricultural plants. In some cases, such substances are in fluid-form (liquid or gaseous phase, as opposed to solid phase).

Apparatus is required to convey the substance from a bulk storage container to the ground.

One example is the injection of anhydrous ammonia ( $\text{NH}_3$ ) (a gas at ambient  
15 temperatures and pressures) into the ground. Normally, the substance is kept under pressure in liquid phase in a large bulk holding container or tank. What are called knives have discharge ends that are dragged through the ground. A valving and distribution system can be selectively operated to convey anhydrous ammonia from the tank to the knives as the knives are dragged through the ground to emplace the fertilizer in the ground.  
20 Nitrogen fertilizer is a major input in terms of cost and energy in production of major crops (e.g. corn, wheat, cotton, rice). Anhydrous ammonia is the most popular form of nitrogen fertilizer application.

Physical properties of anhydrous ammonia can cause it to convert from a high pressure liquid to a mixture of liquid and gas as it travels through application equipment.  
25 The mixture is very difficult to evenly distribute to individual application knives across the swath width of the applicator. These distribution problems may be the cause of over-application. Because liquid ammonia is much more dense than gaseous form, openings that receive greater proportions of liquid ammonia will distribute more nitrogen to their knives than openings that receive greater proportions of gaseous ammonia. This results in  
30 often highly variable application across the applicator swath.

Normally some type of manifold is used to distribute anhydrous ammonia from the tank to a plurality of knives, so that in one pass, a plurality of rows can be fertilized.

During the past 10 years, new low pressure anhydrous ammonia manifolds have been developed. Each manifold has some potential to improve upon the widely varying distribution of the 40-year-old "conventional" radial outlet manifold.

The present inventors conducted studies of several types of commercially available distribution manifolds. Eight manifolds were evaluated during field application at application rates of 84 kg N/ha (75 lb N/ac) and 168 kg N/ha (150 lb N/ac). The actual ammonia stream from each outlet of the manifold was collected and weighed after each run to determine mean, % difference from mean, highest outlet to lowest outlet weight ratio, and the coefficient of variation ("CV") for each run with 11 knife outlets. Results showed that the use of the older "conventional" manifold can result in coefficient of variation or CV values in excess of 30%. Some studies indicate as much as a four-to-one shank-to-shank output variation across an applicator. In general, all the newer manifold designs tested reduced this value, some achieving CV values in the 5% range. But some still have on the order of two-to-one variation between shanks. During application the operator cannot tell if there is over- or under-application. The term CV or coefficient of variation, as used herein, is in percentage as a statistical indicator of variation in output of each manifold. The lower, the better. The coefficient of variation is a well-known indicator. (See, e.g., Steel, R.G., J. H. Torrie, and D. A. Dickey. *Principles and Procedures of Statistics: A Biometrical Approach*. 3<sup>rd</sup> ed. McGraw-Hill Companies, Inc. New York. 1997 Pg. 26-27; and ASAE (American Society of Agricultural Engineers) S386.2 DEC98 *Calibration and Distribution Pattern Testing of Agricultural Aerial Application Equipment*, ASAE-The Society for engineering and agricultural, food, and biological systems, 2950 Niles Rd., St. Joseph, MI 49085-9659; and ASAE (American Society of Agricultural Engineers) S341.3 FEB99 *Procedure for Measuring Distribution Uniformity and Calibrating Granular Broadcast Spreaders*, ASAE-The Society for engineering and agricultural, food, and biological systems, 2950 Niles Rd., St. Joseph, MI 49085-9659).

The above-mentioned testing of existing distribution manifolds show there is room for improvement in distribution from the holding container to the application knives. Even a reduction of a few percent of anhydrous ammonia use by improved application equipment and methods could materially decrease the amount of nitrogen release (including into surface and ground water resources) as well as cost to the producers. Some of the existing

distribution systems tested (on a three-point DMI model 3250 anhydrous ammonia applicator) include:

Rotaflow (™) from H.I. Fraser Pty LTD (Sydney, Australia) -- top feed rotary with flow of material through impeller, not outside it.

5 Equaflow (™) from PGI Intl. -- Rotary outlets with internal cavity size manually controlled by user.

Vertical Dam designs (small and large, cotton or corn rings) from Continental NH<sub>3</sub> Products -- ammonia enters from side and swirls into radial outlets.

10 Conventional manifolds (Model 3497) from Continental NH<sub>3</sub> Products (one with mixer; one with nipple; one with street elbow). Also, a COLD-FLO® System 16 (#20340 canister and separate 16 outlet distribution manifolds.) Also, side entry linear and tee entry linear manifold designs and a FD-1200 (CDS John Blue Co.) were tested.

15 There is a need for optimization of distribution. Development of such a manifold is vital to the future use of this fertilizer form in precision agriculture applications including variable rate application and late spring side dressing of ammonia. Existing manifold designs exhibit noticeable variation as they distribute anhydrous ammonia fertilizer to each of the injection knives on the toolbar applicator. This can lead in the field to nitrogen deficiencies, adversely affecting yield or excesses, adversely affecting environmental quality.

20 Four measures of variability among outlet distribution were computed. Average outlet difference is the average absolute difference in kg(lb)NH<sub>3</sub> of all outlets from the mean output of all outlets for a particular test plot. The average percentage outlet difference is the average of absolute outlet difference from the mean outlet output expresses a percentage of a mean outlet output. This percentage measures use to indicate the average percentage each outlet is from the mean application rate and to normalize variability based on the ammonia collected during each plot run. High/low ratio is the ratio of the ammonia weight from the outlet with the greatest output to the outlet with the least output for a specific application. Coefficient of variation (CV) among the outlets was also included.

30 Variability among entry methods for the conventional manifolds was different for the lower application rate but at the higher rate, all conventional manifolds had equal

variability. The COLD-FLO® manifold had greater variability than all other manifolds tested. The lowest variability across the outlets was measured with the Rotaflow(™) and small-housing vertical-dam manifolds at both application rates. Although the small-housing vertical-dam had low variability, it also had a lower flow rate through the manifold and subsequent lower application rate for the same regulator setting. A general trend of decreasing variability with increasing manifold pressure was seen.

Further discussion of problems with present distribution manifolds is set forth at "Rate Variability of Anhydrous Ammonia Applicator Equipment", ISU Extension publication PM-1747, and "Improving the Uniformity of Anhydrous Ammonia Application", Iowa State University, University Extension publication PM 1875 (June 2001), both incorporated by reference herein.

Vertical dam manifolds and the COLD-FLO® system try to solve the gas/liquid mixture problem by separating gas and liquid phases and metering equal portions of each to each knife.

### III. BRIEF SUMMARY OF THE INVENTION

The present invention relates to a distribution manifold for distributing a gas and liquid phase substance from a single inlet to multiple outlets with reduced distribution variation. In one aspect of the invention, an apparatus comprises a body, an inlet, a plurality of outlets, a fluid pathway between inlet and outlets, and mechanism to move the exit of the pathway in a controlled manner past the outlets. In one aspect, the mechanism is an impeller, being rotatable and having a surface at an angle to flow of the substance (e.g. external flighting or a spiral groove), allows the substance to pass from the inlet and at the surface as the impeller rotates, to then distribute the substance to the outlets. Impeller rotation can be induced by pressure of the incoming substance against the impeller surface(s). The fluid pathway can be multiple pathways. Optionally, rotation can be powered by a motor or other actuator.

The method according to the invention includes placing, in the delivery path of the substance, a member that moves the substance pathway, by the outlets at a controlled rate.

In one aspect, the member rotates in the path of the substance prior to the substance

reaching a plurality of distribution outlets. Some embodiments of the pathway can include an external pathway on a rotating member and/or one or more spiral grooves.

Improved accuracy in distribution manifolds can result in lower ammonia application rates resulting in less nitrate leaching and reduced yield variability.

- 5 Recommendations can also be made to achieve the most even fertilizer distribution at different application rates.

#### **IV. BRIEF DESCRIPTION OF THE DRAWINGS**

10 Figures 1A-C illustrate in perspective, exploded, and sectional views respectively, an apparatus according to one aspect of the invention.

Figures 2A-G illustrate in various views the main body of the apparatus of Figures 1A-C. Figures 2C-2E are generally to scale.

15 Figures 3A-F illustrate in various views an impeller which is positionable inside the body of Figures 2A-G for the apparatus of Figures 1A-C. Figures 3C-3F are generally to scale.

Figures 4A-H illustrate various views of a bearing assembly used with the impeller of Figures 3A-F relative to the body of Figures 2A-G for the apparatus of Figures 1A-C. Figures 4B-4H are generally to scale.

20 Figure 5 is an isolated perspective view of a cover for the body of Figures 2A-G of the apparatus of Figures 1A-C, and which supports the bearing assembly of Figures 4A-H.

Figures 6A-C show in more detail the cover member of Figure 5 in isolation. Figures 6A-6C are generally to scale.

25 Figure 7 illustrates in perspective view the impeller of Figures 3A-F installed in the body of Figures 2A-G, and also illustrates fittings adapted for connection to individual hoses or conduits to individual injections knives.

Figure 8 is a partial sectional elevation of an alternative embodiment of the invention.

#### **V. DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT**

30 For a better understanding of the invention, one exemplary embodiment will now be described in detail. It is to be understood that this is but one form the invention can take

and does not limit the scope of the invention. Variations obvious to those skilled in the art will be included within the invention.

#### **A. General Environment of Use of the Invention**

An embodiment of the invention is here referred to as distribution manifold 10.

5     Manifold 10 includes an input adapted to be connected to a pressurized source of anhydrous ammonia (see Figure 1B), and has a plurality of fittings 80 radially distributed around the manifold body 12 (see Figure 1A) that can be operatively connected to hoses which, in turn, are connected at distal ends to individual injection knives for an anhydrous ammonia injection system (see Figure 1B where, for simplicity, just one fitting 80 from an  
10     outlet 22 is diagrammatically illustrated connected by a hose to an injection knife).

       Distribution manifold 10 can be used for anhydrous ammonia fertilizer for agriculture. It uses an impeller 30 that spins with the movement of the ammonia past it; the pressurized fluid creates a force against the angled flighting or groove of the impeller, causing the impeller to spin. The impeller 30 slings the ammonia radially outward to a set  
15     of outlets evenly spaced around the manifold. The movement of the impeller more evenly distributes the ammonia to the outlets 22 than existing designs. Most of the existing manifolds have radial outlets, but without an impeller to distribute the ammonia. The more even the distribution of ammonia to the manifold outlets, the more even the distribution of fertilizer across the field. With uneven distribution, producers are in the habit of over-  
20     applying to ensure a minimum application rate. The use of this design could reduce the application of ammonia while still meeting yield goals.

       Manifold 10 could be installed on cooperative-owned toolbars and rented to member producers. A few producers own their own anhydrous ammonia toolbars, but the majority are rented or a custom applicator is hired to do the application. Two main  
25     purchasers would be cooperative and custom applicators.

#### **B. Specific Apparatus Structural Components**

       More specifics of distribution manifold 10 can be seen in the drawings. Figures 1A-C illustrate the pieces of distribution manifold 10. Figures 2 through 7 illustrate other specifics.

## 1. Body 12

The main pieces include cylindrical body 12 (e.g. aircraft grade Aluminum 6061, approx. 12 inches long, 6 inches O.D.) having an inlet 18 connectable by well-known components to an anhydrous ammonia source. In this embodiment, the length of manifold  
 5 body 12 is approximately one foot long, and its diameter is generally in the proportion indicated in Figures 1A-C and 2A-G.

Manifold body 12 includes a central bore 24 connecting inlet 18 to a conical cavity 26 (see Figure 1C and Figure 2G). Radially disposed outlets 22 exist at end 16 of manifold body 12 (see also Figures 2A-G). Outlets 22 extend from the inside of the conical cavity  
 10 26 to the outer exterior of manifold body 12. As shown in Figures 1A, 2A-B, and 7, fittings 80 (well known in the art) can be operatively connected to outlets 22, and in turn each can be operatively connected to a hose or conduit to an injection knife(also well known in the art).

## 2. Impeller 30

An impeller 30 is insertable into conical cavity 26 of manifold body 12. In this  
 15 example it is made of solid glass-impregnated Teflon ® (25% impregnated with glass beads). Such material is relatively easy to machine and has relatively low change in volume over a substantial temperature range. It is approximately 4 inches diameter at its base. It serves as an impeller that is relatively freely rotatable once installed in position in  
 20 response to pressure of fluid (liquid or gas phase) through conduit 24. Spiral grooves or flighting 34 on the exterior of impeller 30 (a conical member which closely matingly conforms to cavity 26--the slope of the exterior of impeller 30 and the slope of conical cavity 26 are the same), provides a fluid pathway from bore 24 to a distribution groove 36 in impeller 30. In this embodiment there are three spiral grooves (each approximately 1.25  
 25 rotations and 120° apart on the exterior of the impeller) (See, e.g., Figure 3D). Thus the NH<sub>3</sub> has three spiral groove paths to enter and traverse between the tip of impeller 30 and its base (at distribution groove 36). Distribution groove 36 is positioned in the plane of radial outlets 22 of manifold body 12 and is in concurrent fluid communication with all outlets 22.

30 The distribution groove 36 sits at exactly the elevation of outlets 22 when the system is in operation and pressure of incoming fluid has pushed impeller 30 up to the top

of body 12 (There is a small amount of longitudinal tolerance between impeller 30 and body 12). Distribution groove 36 is fed by the exit ends of the three spiral grooves as they move material up from inlet 24. The fluid pathway between inlet 24 and outlets 22 here is therefore split into three separate sub-pathways or spiral grooves that can be called supply  
5 grooves. The supply grooves provide three sources to the distribution groove 36, at 120° intervals. This allows for more even filling of distribution groove 36, than a single source would and attempts to provide constant material quality (defined at a ratio of the material in the two masses; quality = 1 would be all liquid, 0.0001 would be all gas), mass, and pressure to all outlets 22. Even if impeller 30 were to stop rotating, it provides three outlets  
10 to distribution ring or groove 36 and then to outlets 22.

Impeller 30 is shown in more detail in Figures 3A-F. Figure 3A shows, in perspective view, a rough prototype model. As shown in Figure 1C, once assembled, impeller 30 fits in conical cavity 26. An end plate 60 (see also Figures 5 and 6A-C) is securable to manifold body 12 by bolts 70 through bolt holes 72 into threaded apertures 25  
15 in the face of end 16 of manifold body 12. An elastomeric O-ring 66 (e.g. Viton ® or buna-N) cooperates with a raised embossment 62 in end plate 60 and an O-ring receiving race 23 in the end base of 12 to provide a seal between body 12 and end plate 60 once assembled.

### 3. Bearing Assembly 40 Generally (Including Ball 50)

20 Impeller 30 is held in rotatable fashion as follows. A bearing apparatus (generally referred to at reference numeral 40 and shown more specifically at Figures 4A-H and Figure 5), includes a threaded end 44 which extends through center opening 64 in end plate 60 and can be secured there by nut 68. An opposite end includes opposite flattened portions 55, and a concave end face 53.

25 A pin 46 is interference fittable into a longitudinal receiver bore 57 at the center of concave face 53 (see Figure 4A).

A bearing ball 50 (e.g. solid virgin Teflon ®) is insertable by interference-fit onto the other end of pin 46 by forcing pin 46 into bore 51. Bore 51 is completely through ball 50, but when assembled onto pin 46, pin 46 does not extend completely through ball 50.

30 Ball 50 is inserted on pin 46 to where it seats into concave 53. The curvature of concave 53 matches the exterior curvature of ball 50. The interference fit of pin 46 in bore 57 and



ball 50 onto pin 46 holds ball 50 in place and deters rotation around pin 46. But this combination allows relatively easy removal and replacement of ball 50 (e.g. if it frictionally wears over time) by simply pulling ball 50 off of pin 46 (overcoming the interference fit).

As illustrated in Figure 1B, a machine screw 52 is insertable into a central bore 33 (see Figure 3E) in impeller 30 and can be threadably screwed into threaded, reduced-diameter bore 35 at the inner end of central bore 33. Screw 52 has a head that has a machined concave to match the curvature of ball 50. The concave in the head of screw 52 essentially works as a bearing surface for ball 50.

Bearing assembly 40, with ball 50 installed on pin 46 and seated in concave 53 (see Fig. 4A), can be inserted into center bore 33 of impeller 30. The diameter of ball 50 is slightly smaller than the diameter of bore 33 such that it passes into bore 33 without interference. Assembly 40 can be pushed down bore 33 until end plate 60 abuts the end of body 12. As can be appreciated, the amount screw 52 is threaded into bore 35 determines how close its head will be to ball 50 when manifold 10 is assembled. Screw 52 is adjusted so that its head, specifically the concave of its head, is closely adjacent ball 50 (e.g. approximately 1/8 inch). An elastomeric O-ring 48 (e.g. Viton ® or buna-N) can be installed in channel 47 of bearing assembly 40 to seal off opening 64 in end plate 60 (see also Figure 4A-G and Figure 5).

By referring to Figure 5, once bearing assembly 40 is secured to end plate 60 and impeller 30 is in conical cavity 26, end plate 60 (with bearing assembly 40, including ball 50) is inserted, as described, such that ball 50 is positioned in bore 33 of impeller 30 and end plate 60 is secured to manifold body 12. As can be appreciated, the small tolerance between the head of screw 52 and ball 50 is designed so that when pressurized  $\text{NH}_3$  enters bore 24, it travels up bore 24 and impacts the nose of impeller 30, and enters the spiral groove of impeller 30. This creates an up-force on impeller 30 (in operational position it is vertically disposed, nose down in body 12) as the pressurized fluid hits the rifling or flighting (or walls of spiral groove 34) of impeller 30 which are at an angle relative to the flow path of fluid from inlet 24. This essentially lifts impeller from being seated in conical cavity 26 and moves impeller up longitudinally until the concave head of screw 52 in impeller 30 comes into abutment with ball 50. As indicated above, there is about 1/8 inch play. When screw 52 is in abutment with ball 50, the ball partially seats in the concave in

the head of screw 52 and this is essentially the only point of contact between impeller 30 and any other structure. Thus, this interface is the rotation bearing for impeller 30. The force of the fluid acting on the walls of spiral groove 34 of impeller 30 causes impeller 30 to rotate on screw 52 around ball 50. Telfon ® ball 50 presents a relatively low coefficient of friction to metal screw head 52.

Again, screw 52 can be adjusted (before assembly, or the assembly can be disassembled and screw 52 adjusted before re-assembly) along the longitudinal axis of the assembly 10 such that there is a slight longitudinal play between ball 50 and the head of screw 52.

Referring also to Figure 7, which shows impeller 30 in conical cavity 26, this arrangement allows relatively free-spinning of impeller 30 in manifold body 12 but seals any escape of fluid from manifold body 12 other than through outlets 22 and fittings 80.

### **C. Operation**

In operation, distribution manifold 10 is connected to an anhydrous ammonia source through inlet 18. Threaded bores 20 on the end face of end 14 of manifold body 12 can be used to mount distribution manifold 10 to an implement. Fittings 80 are installed in each radial outlet 22 in a sealing fashion. Hoses to injection knives are connected to fittings 80. By appropriate valving or other control systems, anhydrous ammonia from its source flows into inlet 18, down conduit 24, and impacts the apex of impeller 30, entering the channel formed by flighting or spiral groove 34. The pressure (e.g. approx. 10-70 psi - pressure varies, including as a function of tank pressure and field conditions such as temperature) of the anhydrous ammonia source relative to the angle of flighting or spiral groove 34 causes impeller 30 to spin. The anhydrous ammonia follows flighting or spiral groove 34 up to distribution groove 36 in impeller 30, which is aligned with radial outlets 22, essentially distributing anhydrous ammonia to each outlet 22 in sequence at the rate of spin of the impeller 30.

A tachometer 83, connected by wire 84 to a read-out or other device, can be positioned on end plate 60 and used to monitor the speed of the impeller 22 (see Figure 5).

In the exemplary embodiment, the design of impeller 30 includes a minimum of one rotation of flighting or spiral groove (here there are three end-to-end grooves each with slightly over one revolution from start to finish) and an angle of flighting or spiral groove

relative to the longitudinal axis of impeller 30 that was not very steep (higher angle) or very shallow (lower angle). A basically middle of the road angle was selected with the goal to have about one-half of the force of fluid pressure pushing longitudinally or "forward" on impeller 30 and about one-half pushing sideways. This has been found to work, at the pressures normally encountered, to begin impeller 30 spinning (from its resting state) and to maintain it spinning.

Also, the sum of the cross-sectional areas of the flightings equals the cross-sectional area of the inlet of flow (the cross-sectional area of bore 24 and opening 18--both of which are approximately 3/4 inch diameter). Also, the sum of the areas of each of the thirteen outlets 22 is equal to the cross-sectional area of the fluid inlet to manifold 10.

It has been found that the higher the pressure retention in the manifold, the better the distribution of the  $\text{NH}_3$ . Expansion areas are kept to a minimum to reduce pressure loss in the manifold body; however some variation is not necessarily materially detrimental. Pressure loss will result in temperature loss as the ammonia moves towards the boiling point at  $-33^\circ\text{C}$ . With anhydrous ammonia, this can mean conversion of the fluid phase to gas phase (vapor). So, again, it is believed advantageous to keep the cross sectional area constant from inlet to outlets for better distribution and lower losses.

#### **D. Options and Alternatives**

It is to be understood that the present invention can take many forms and embodiments. Variations obvious to those skilled in the art will be included within the invention, which is solely described by the claims herein.

The precise size and configuration of distribution manifold 10 can be varied according to need. As indicated previously, dimensions for exemplary embodiments have been given and/or can be derived from the description and figures.

Other than the Teflon® parts, most of manifold 10 is made from aluminum. However, the materials can be varied. For example, it is preferable that as low a coefficient of friction as possible be created for bearing assembly 40. Materials other than Teflon® could be used.

For further example, it is believed that manifold 10 can be scaled up or down and be effective.

Also, it is possible to cause powered rotation of impeller 30 by mechanical means (e.g. mechanical drive, electric or gas-powered engine, magnetic drive, etc.). Figure 8 diagrams a manifold 10 like previously described but with an electric motor 90 (e.g. variable speed) operatively connected by motor drive shaft 92 to impeller 30. A seal 94  
 5 sends shaft 92. However, it is presently preferred to have impeller rotation powered by pressure of the anhydrous ammonia itself. If powered otherwise, it could require a seal of a moving component (e.g. an axle) which is difficult to do. It also is a safety issue with anhydrous ammonia.

10 The impeller could have other groove configurations (e.g., one or more spiral groove(s) and at different pitches or widths).

More or less outlets 22 are possible, and outlets can be plugged if not used.

#### **E. Design parameters**

As can be appreciated, the invention can take different embodiments and designs. Different desires and needs can result in different design criteria and goals. To assist in an  
 15 understanding of design choices, and by way of example and not limitation, the following description is provided with respect to an embodiment having the following design goals for the manifold:

1. The design must be able to be machined from commonly available material stock.
- 20 2. The manifold must be able to simply replace an existing manifold, without the addition of new plumbing or controller systems.
3. The manifold should require no input from the operator, i.e. the operator should not have to “set” the manifold.
- 25 4. A single design unit should handle all application rates up to 224 kg N/ha (200 lb N/ac, 4000 lb NH<sub>3</sub>/h on the test applicator), as this is a common high application rate in Midwest corn.

This design incorporated an impeller with rifled grooves that would rotate, either driven externally or allowed to spin from the impact created by the flow of the NH<sub>3</sub>.  
 30 Allowing the material to spin the impeller reduced sealing problems, eliminated the need for an electrical supply for the manifold, and reduced costs. The spinning created by the

NH<sub>3</sub> flow was hoped to be sufficient to evenly distribute the material to outlets arranged radially around the base of a cone shaped impeller. With an impeller driven by material flow as the basic design selected, additional design parameters were evaluated.

Research showed consistently that existing manifolds with a cavity in the manifold where the NH<sub>3</sub> could expand had poor distribution. This expansion area allows an initial pressure, causing vapor production through boiling of the NH<sub>3</sub>. The present manifold was designed so the cross sectional area for NH<sub>3</sub> flow would remain constant from the point at which material entered through a standard Acme fitting to the point where it left the manifold at the outlets.

For distribution systems using tank pressure to provide NH<sub>3</sub> flow, pressure drop through fittings and the regulator had been shown to be significant. This results in a mix of NH<sub>3</sub> in the liquid and vapor phases at the manifold. To reduce the possible effect of uneven distribution due to two-phase flow of the material, it was decided that the material should enter the manifold from the bottom and exit at the top. Gravity would help the chamber to fill with liquid from the bottom up. Vapor bubbles would migrate to the top of the manifold before moving out the outlets.

A test applicator used was outfitted for 11 outlets. In addition, the instrumentation to collect the temperature and pressure data for the manifold required an additional two ports. Thus, thirteen ports were used for the manifold design. Hose barbs that were 9.5-mm (0.38-in) outside diameter and 7.1-mm (0.28-in) inside diameter, common on NH<sub>3</sub> manifolds, were used to standardize the manifold to mate with existing hoses.

A 19.1-mm (0.75-in) Acme NH<sub>3</sub> fitting was selected as the inlet fitting. The 19.1-mm fitting was selected as it would allow for the flow rate necessary for the application rate goal without the excess area of the common 25.4-mm (1.0-in) Acme fitting. The cross sectional area of the inlet on the 19.1-mm fitting was 285-mm<sup>2</sup> (0.430-in<sup>2</sup>). Throughout the design, the total cross-sectional area through which the material flowed was limited to this value if possible.

The sum of the groove area in the impeller, and the sum of the area of the 13 outlets were set within an acceptable range of 270 to 300-mm<sup>2</sup> (0.421 to 0.438-in<sup>2</sup>). This range allowed for any limitations in machining capability. Outlet ports drilled with a 5.16-mm (13/64<sup>th</sup>-in) drill resulted in a total outlet area for 13 ports of 272-mm<sup>2</sup> (0.422-in<sup>2</sup>).

Based on readily available material and the funds for manifold development, aluminum was selected for the manifold body, and Teflon<sup>®</sup> was selected for the impeller cone.

Solid round stock of 6061-T6 aluminum 30.5-cm (12.0-in) in length and 15.3-cm (6.0-in) in diameter was selected as the blank for the manifold housing. This material was selected because of low cost, ease of machinability, low weight, and high heat conductance. Common concerns about aluminum being eroded by reacting with additives to NH<sub>3</sub> (primarily nitropyrin) were considered, but for the extent that any prototype would be used, aluminum was considered a suitable material.

For the impeller cone, Teflon<sup>®</sup> impregnated with 25% glass beads was selected and round stock 30.5-cm (12.0-in) in length and 10.2-cm (4.0-in) in diameter was used to produce two impeller cone blanks. The addition of 25% glass beads impregnated into virgin Teflon<sup>®</sup> hardens the material making it easier to accurately machine, and reduces the dimensional change of the material with temperature fluctuations.

The lid for the manifold housing was cut from one end of the round stock and finished to 1.105-cm (0.435-in) thickness. The lid was attached with 13 allen head screws and a Viton O-ring, 11.4-cm (4.5-in) in diameter, and was set in a machined groove in the housing to provide a seal. A 1.3-cm (0.5-in) diameter axle was installed into the lid for the impeller to spin on. The axle also used a Viton<sup>®</sup> O-ring to seal into the lid. A 1.3-cm (0.5-in) virgin Teflon<sup>®</sup> ball was machined to a diameter of 1.23-cm (0.485-in) and pinned to the end of the axle to provide a low friction bearing surface for the impeller cone to run on. At the bottom of the axle recess in the impeller cone, an allen head screw was machined with a concave cupped head to match the radius of the ball on the axle. This increased contact surface area and reduced wear. In addition, the threads of the screw allowed adjustment of the clearance between the lid and the base of the cone.

The length of the impeller cone cavity in the manifold housing was set at 12.7-cm (5.0-in) due to machining limitations. To allow sufficient area for the O-ring seal with the lid and the 13 lid sealing screws, the width of the cavity was limited to 9.91-cm (3.90-in). With an inlet diameter of 1.88-cm (0.74-in), the slope of the manifold housing cavity face was calculated as 17.5 degrees.

Three impeller cone designs were fabricated for testing. The first two machined from the raw stock material, and the third a modification of the first design. Design #1 used a tapering cone with a 20.5 degree taper with a single 3.2-mm (0.125-in) square groove completing 3.25 revolutions before reaching the base of the cone. The taper  
5 between the housing and the cone retains a constant cross-sectional area as the material moves up the cone. Design #2 used the same taper as the housing, 17.5 degrees, with three 9.53-mm (0.375-in) square grooves that make 1.25 revolutions each. In addition, #2 had a 6.4-mm (0.25-in) square groove cut into the impeller at the elevation of the outlets. Design #3 was the same as Design #1 with the original groove cut out to 9.53-mm (0.375-in)  
10 square. The increased groove of #3 was tried after initial tests show that impeller #1 was not turning while  $\text{NH}_3$  was flowing through the manifold.

The base width of each cone was cut to 9.779-cm (3.850-in), resulting in a clearance of 0.191-cm (0.075-in) between the cone and housing and this clearance allowed the cone to move vertically on the axle. The cone was not fixed to the axle, rather it was  
15 allowed to float up due to the force of the incoming  $\text{NH}_3$ . When the incoming material stream forced the cone to raise off the housing, the  $\text{NH}_3$  moving through the rifled grooves should cause the impeller to spin. The  $\text{NH}_3$  would move up through the grooves and be distributed to the outlets near the base of the impeller.

To determine if the impeller was spinning and if so, how fast, a magnetic pulse  
20 tachometer was installed in the lid of the manifold housing. An A103-003 Tachometer (Dynapar brand, Danaher Controls, Gurnee, IL) was coupled to a 103SR13A Hall Effect Position Sensor (Honeywell, Freeport, IL). The sealed sensor, designed for harsh conditions, was installed in the lid of the manifold and four bi-polar magnets were installed into the top of each of the impeller cones. The tachometer logged pulses per second, and  
25 with 4 magnets on the cone, resolution was 15 revolutions per minute (rpm), and sensor output capability allowed outputs of up to 450 rpm.

Plans were drawn for manufacturing and modified as necessary due to machining limitations. Four threaded holes on the bottom of the housing were used for mounting the manifold to the applicator.

The bearing end of the axle was cut with a concave radius to match the bearing ball. In addition, the ball was attached only with the friction fit between the pin and the ball. This allowed for replacement of the bearing ball.

5 A recessed lip was machined into the edge where the tapered cavity in the housing met the top face of the housing. To match this lip and create a tight self-aligning fit, 0.178-cm (0.070-in) thickness was removed from the face of the lid to match the housing. The hole for the hall effect sensor was drilled through the lid and threads to match the sensor were tapped into the lid. The threads of the hall effect sensor were sealed with Loctite™ thread sealer to prevent NH<sub>3</sub> leakage.

10 Four holes in the top face of the impeller were created as locations for the hall effect sensor magnets. A machined channel around the outside of the axle recess in the cone was added to reduce the weight of the impeller cone after the initial testing phase.

A clearance problem between the cone and the manifold housing seemed to prevent the impeller cone from spinning freely in Design #2. The removal of approximately 0.127-cm (0.050-in) of material from the diameter of the impeller at and around the area of contact resolved the problem. A set of field tests was run to verify that the impeller was spinning during application and was performing as designed.

Of the three Designs described, Design #2 was selected as the best design option.

15 Other design considerations are discussed earlier in this description. A further design consideration, for one embodiment, is that width of fluid pathway between inlet and plurality of outlets be on the order of two to one.

In another aspect, the design prefers to give each of the plurality of outlets equal opportunity to have NH<sub>3</sub> come out all the time. One way to do so is to spin the impeller so that NH<sub>3</sub> enters the entries to the impeller spiral groove(s), moves through the spiral groove(s), and exits the exit(s) of the spiral groove(s) into the distribution groove, which is essentially a void or space that is simultaneously or concurrently in fluid communication with all the plurality of outlets from the body. Thus, the rotating exit(s) of the spiral groove(s) of the rotating impeller is directing NH<sub>3</sub> to the distribution groove -- and thus presenting a substantially equal opportunity for NH<sub>3</sub> to each outlet concurrently. The goal is to present the same amount of substance, at the same pressure, concurrently to all the plurality of outlets from the body. Here this is done by spinning the material in a type of



buffering action in the spiral groove(s) of the spinning impeller and then directing the material from the spinning impeller to the annular distribution groove.